A Note on the Electrical Polarization in Quartz and Perthite

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A Note on the Electrical Polarization in Quartz and Perthite

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Abstract

The current after application of a given potential was measured for quartz or perthite. In the case of quartz, the phenomena are expressed by the formula ; $i=At^{-n}$, the currents decrease with time, but the ratio of its decreasing is less at higher temperatures than at lower. For perthite, it is found that the current after switching operation increases with time in the lower temperature region, while, it becomes to decrese as in quartz or general dielectrics when the temperature is raised above about 500°C. In the both cases of quartz and perthite, no polarization is found at sufficiently high temperatures,

1. Introduction

In case of geophysical investigation of rocks, it is desire to carry out the experiments at high pressures and high temperatures as predominating the earth's interior. For the electrical property of rocks, the satisfactory data have not been obtained under such conditions because of various difficulties. At first, we have studied on the electrical conductivity of rocks in the higher temperature region, [1] [2].

There are a number of methods of measurement for high resistance materials like rocks. But, if we desire to observe the thermal variation of the electrical conductivity by using the direct current, a matter of first consideration will be the influence of the polarization e.m.f.. Therefore, an experiment concerned with electrical polarization was carried out for the purpose of expecting the behavior of that phenomena in various temperatures.

The variation of the current in a dielectric with time was studied by J. HOPKINSON [3] and the CURIES [4] more than sixty years ago. It was later studied by F. TANK [5] and S. W. RICHARDSON [6] and still later by A. JOFFÉ [7]. And the summary report on the electrical conduction was written by M. F. MANNING and M. E. BELL [8]. As stated by M. F. MANNING and M. E. BELL, the general phenomena of the polarization are as follows : When a potential difference is applied to a dielectrics the current changes with time as shown in Fig. 1. It has not been possible to determin

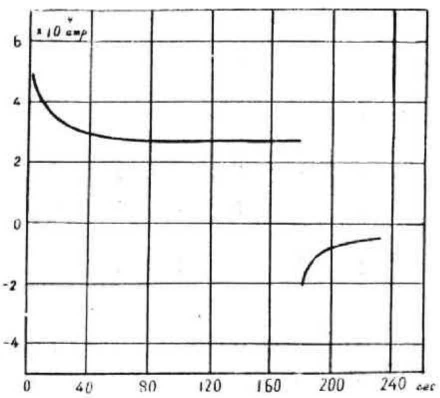

Fig. 1. Charging and discharging currents vs. time. in quartz
Applied field 100 volts
Temperature 316°C

the current at very small time intervals after application of voltage, but all results indicate that it rises very rapidily toward $t=0$. At ordinary temperatures the steady-state value of the current may be reached only after several hours or even days and may be as low as 10^{-4} of that observed initially. If the specimen is short-circuited, it is found that a current, known as the discharging current, flows in the reverse direction. The relations between charging and the discharging currents have been studied in detail by many investigators.

On the other hand, the steady state polarization e.m.f. has been measured by a number of authors [9] [10] for different materials as a function of applied voltage and temperature. In general, the steady state polarization increases with potential but approaches a limit at higher values. The maximum value of polarization e.m.f. for a given applied voltage is smaller for higher temperatures. The general run of the data indicates that the polarization reaches its equilibrium value in a shorter time at higher temperatures. At sufficiently high temperatures no polarization has been found. We attempt, as mentioned above, to examin this phenomena that the polarization changes with tem-

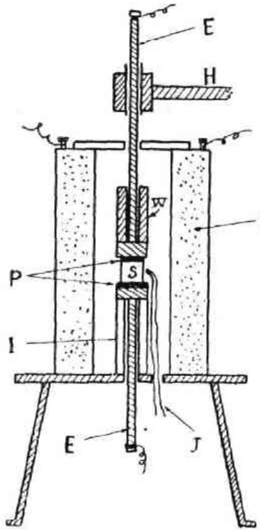

Fig. 2. Diagram showing the part within the electric furnace.
S: specimen P: plate of Pt
W: weight of Iron
E: electrode made of blass
J: thermo-junction F: electric furnace
I: insulater H: supporter

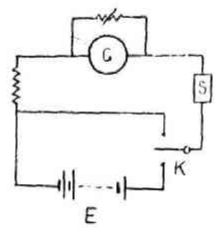

Fig. 3. Circuit used in measurement.
G: galvanometer (sensibility 1.3×10^{-9}amp/mm, period 1.8 sec.)
S: specimen
K: switch
E: battery

perature, and also to apply the results when the electrical conductivity is measured by using direct current at higher temperatures.

2. Methode of experiment

Both quartz and perthite used in measurement are the same place of production, at Suisyôyama in Fukushima prefecture, Japan. The shapes and dimensions are a cube of about one cubic centimeter or a plate of one square centimeter and 0.5 cm thick. The specimen is placed between the electrodes of Pt plate which are set in the electric furnace as shown in Fig. 2. The temperature is changed by controlling the current supplying to the furnace. The Pt-PtRh thermo-junction is used for measurement the temperature. The circuite adopted in this experiment is shown in Fig. 3. Many methods have been studied for measurement the polarization e.m.f.. Most of that are attempted how to observe the current at very small time intervals after application of voltage. On this point, the present circuite may not be satisfactory since the observation cannot be carried out at such small time intervals as 10^{-2} sec. or even one sec. after switching operation. The galvanometer used has too long period for such subject. [The period is 1.8 sec.] Therefore, we intend to examine the later phenomena rather than initial. On the case of discussion about the thermal effect for the polarization, this method will give the sufficient results for the purpose.

All specimens are dried before measurement at 130°C by using a drier for several hours. At lower temperatures, as known already, the electrical behavior is much more complicated than in the higher temperature region. The effect of small amounts of impurities is much more marked and the phenomena depend upon the previous thermal history of the particular specimen. Also, for the value at lower temperatures, the mean of many experimental results is adopted. The treatment of the specimen and the controll of temperature are done carefully as possible at the lower temperatures.

In this measurement, the temperature was changed in the region between about 200°C and 700°C.

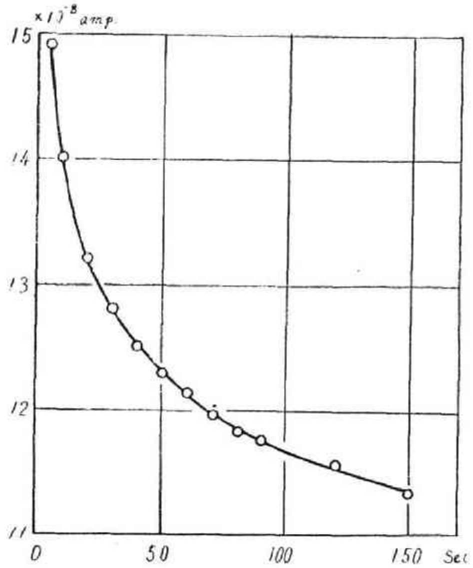

Fig. 4. Charging current vs. time in quartz
Applied field 40 volts
Temperature 509°C

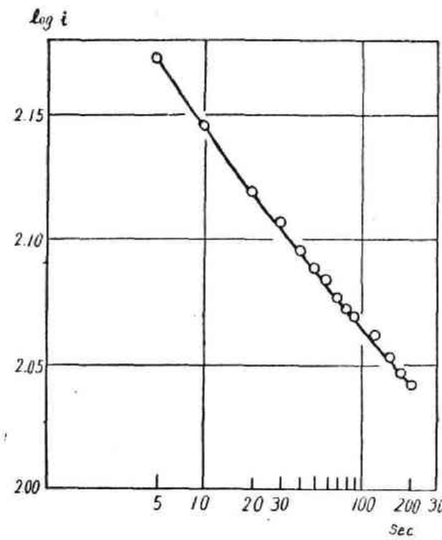

Fig. 5. Log i vs. log$t$ curve in quartz
Applied field 40 volts
Temperature 509°C

3. Results

a) *Quartz* — At first, we shall describe about the results obtained from quartz. This quartz is not ideal crystal and there are some small cracks. In general, a given volatage is applied to a specimen of quartz then the current changes as shown in Fig. 4. If this is shown by log i vs. log t curve, it is found that the linear relation exists between log i and log t. (Fig. 5) Therefore, the relation between i and t is given by the equation as follows ;

$$i = A\,t^{-n} \qquad (1)$$

where A and n are constant respectively. The results Fig. 4 or Fig. 5 and the equation (I) are similar to that obtained by S. W. RICHARDSON [6], F. TANK [5], A. JOFFÉ [9] and others [7] [10]. In Fig. 6 all of the log i vs. log t curves are plotted for the same specimen, but for different voltage. It is interesting to note that since the curves are paralell, only A and not n is a function of the applied field. For the value of n there may be some change with applied potential and its tendency is more remarkable at lower temperatures than at higher. This phenomenon is considered as that influenced by small amounts of inpurities or existence of cracks. Consequently, it may be assumed that the values of n are not dependent upon the applied field in such potential region as used in this experiment.

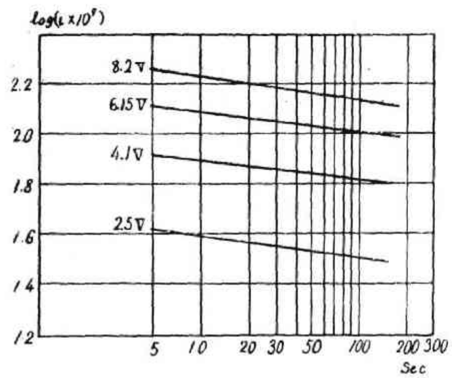

Fig. 6. Charging currents vs. time in quartz at different voltages (temperature 550°C)

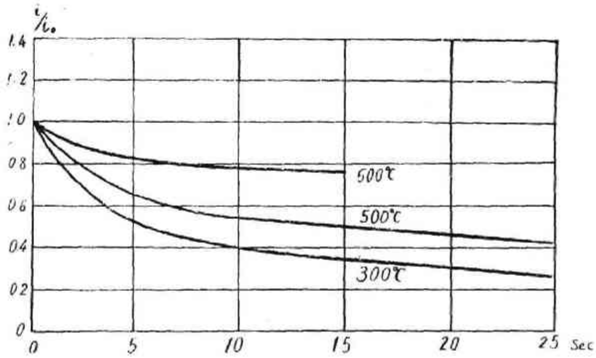

Fig. 7. The decreasing ratio of charging currents at different temperatures (Quartz)

Let us consider the values of n in different temperatures. The values change with emperature as shown in Fig. 7 and Table I. From log n vs. T curve in Fig. 8, it is found

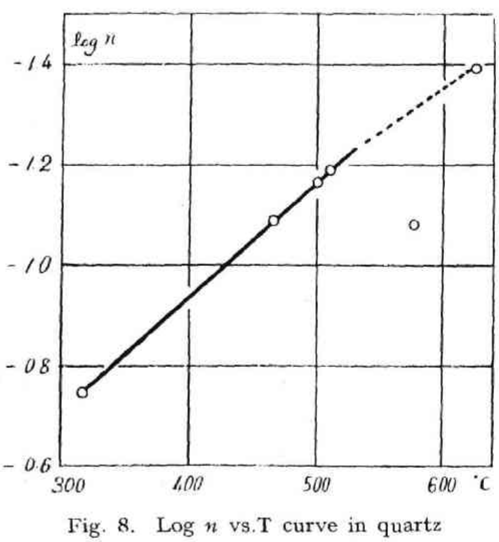

Fig. 8. Log n vs.T curve in quartz

Table 1.

Temperature (C)	316	465	508	575	624
n	0.182	0.081	0.066	0.083	0.040

that the relation between n and absolute temperature T is given by a formula as follows.

$$\log n = -\alpha T + \beta \quad \text{or} \quad n = Be^{-\alpha T} \qquad (2)$$

where α, β and B are constant respectively. For α, the value is 5.4×10^{-3} approximatly. In Table I, an abnormal value is found at 575°C. This is probably the result caused by inversion of its structure. Also from the facts obtained in this measurement, it is obviously found that the polarization e.m.f. decreases with rising in temperature and at high temperatures above 600°C its effect will be able to neglect on measureing the electrical conductivity by using direct current.

Further we examined wether OHM's law is sutisfied or not in such regions of temperatures and voltages as in the present case. According to equation (I), if $t=0$ then i equals to A which means the initial current uninfluenced by polarization e.m.f. On the other hand, G. M. VOGLIS [11] suggested that the i vs. t curves could be represented, down to the smallest time observed, by the formula;

$$i = A\ (t + \tau)^{-n} \qquad (3)$$

And in case of mica he showned that equation (3) should be applied in the time region being from 10^{-2} to one second. For glass, however, the value of τ is so small that the departure from relation (I) could not be found in even such small interval as $10^{-2}<t<10^{-1}$.

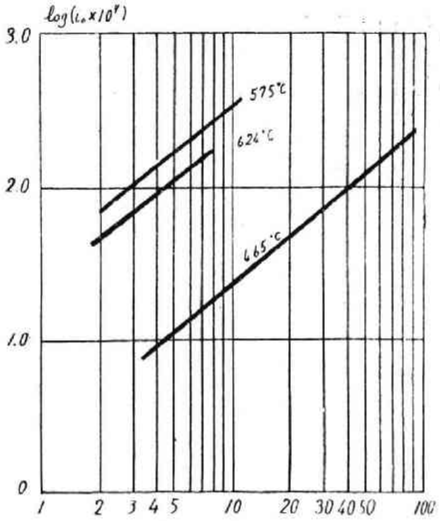

Fig. 9. The relation between the initial currents and applied voltages

Thus, it is unable to know the initial current exactly. We, therefore, assumed that the relation (I) is satisfied at all time intervals, then we can know the initial current numerically from the relation (I) determined by experiments at the large time intervals. In Fig. 9, the relation between

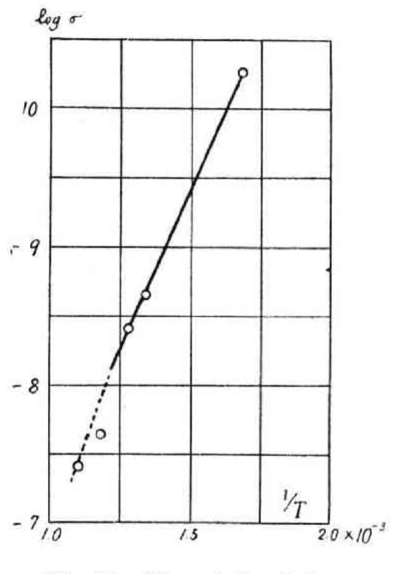

Fig. 10. The relation between electrical conductivity and temperature.

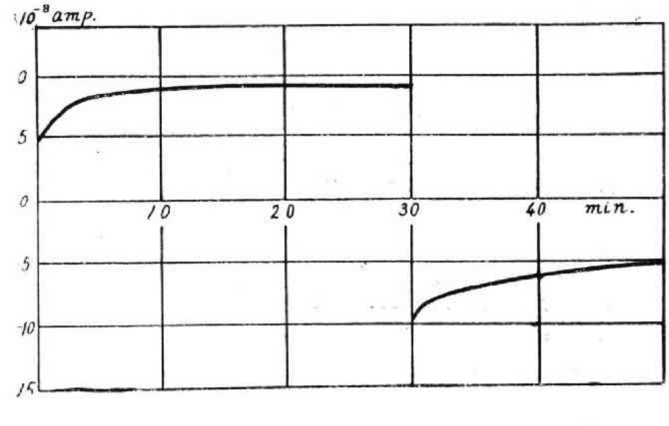

Fig. 11. Charging and discharging currents in perthite. Applied field 785 volts Temperature 300°C

A and applied voltage is shown, we see it is represented by the formula as follows ;

$$A = k\ V^m \qquad (4)$$

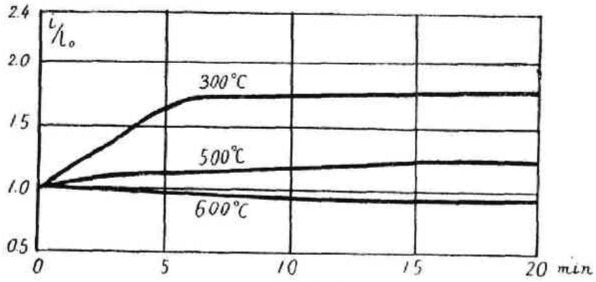

Fig. 12.

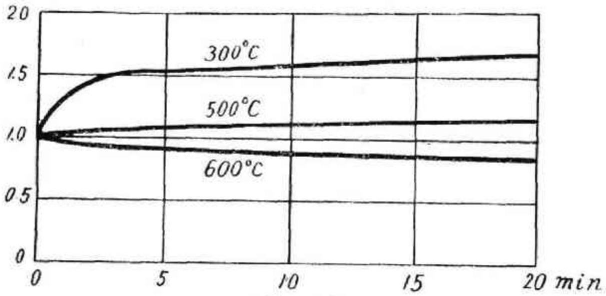

Fig. 13.

Figs. 12, 13. The variation of charging currents with time at different temperatures in perthite. specimen 1. (Applied field parallel with [100] plane)

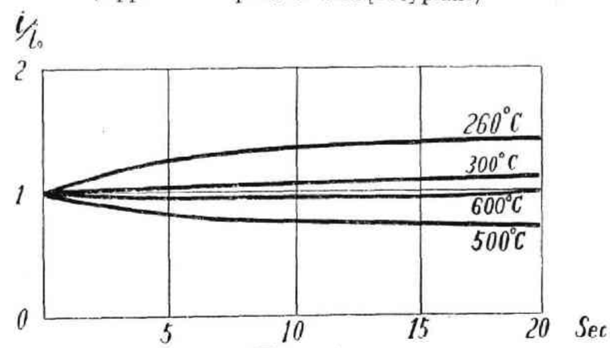

Fig. 14.

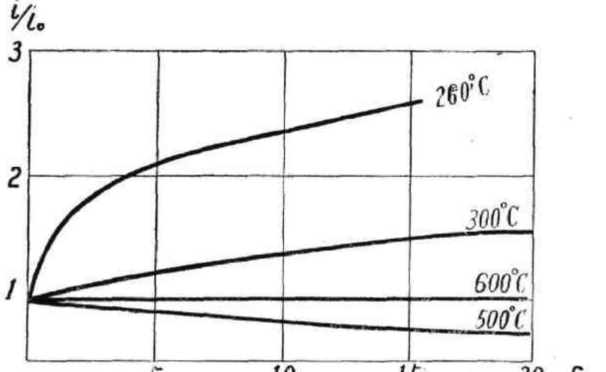

Fig. 15.

Figs. 14, 15. The variation of charging currents with time different temperatures in perthite. specimen 2. (Applied field perpendicular to [100] plane)

where k is a constant which means an electrical conductivity, and m is a constant. In the present case, m has the value 1.035 so it may be concluded that OHM's law is satisfied in the first approximation.

Also the electrical conductivity is derived from k in the relation (4). In Fig. 10, log σ vs. $1/T$ curve is plotted, showing existence the relation given below :

$$\sigma = \sigma_0 \exp(-\gamma/T) \qquad (5)$$

where σ_0 and γ are constants. For this case σ_0 is 7.9×10^5 ohm^{-1} cm and γ has the value 1.04×10^4 cal.

b) *Perthite* — For this sample, a remarkable phenomena were observed in lower temperature region; the current after application of volatge does not decrease but increases with time against expectation. But if the specimen is short circuited after reaching to steady state current, it is found that a discharging current flows as shown in Fig. 11. We shall show only the phenomena observed and not discuss about the results since it is cared that the problems remain to examin in more detail. Denote i_0 the initial current after closing the switch and i the current at any time, then the ratio i/i_0 changes with time for various temperatures as shown in Fig. 12 to Fig. 15. In these figures, the abnormal changes are found generally in the region of lower temperatures and its rate of increasing with time decreases as rising in temperature. When the temperature rises to a point, no polarization is found apparently. However, on reaching to such a state, if the specimen is short-circuited the discharging current will be still observed. Further raising the temperatur above the point, the charging current begins to decrease with time as observed in quartz, then the decreasing ratio of the current increases with temperature and reaches to a limit finally. In the region of higher temperatures than that having the maximum value of decreasing ratio, the current changes along the same process as in case of quartz, namely at enough high temperature the polarization e.m.f. is so small as it is negligible.

The phenomena mentioned above were confirmed for a number of specimens cut off from the same sample of perthite. All results, as showne in figures, exhibited nearly same behavior. These facts may be found by chance that we happend to use the material having very special properties, or may be able to exist in more general cases. On this subject, it remains to study in future.

4. Summary

When a potential difference is applied to a specimen of quartz the current changes with time and the phenomena are expressed by the formula as follows ;

$$i = A\, t^{-n},$$

where A is a constant dependent upon applied voltage, n is independent of voltage but a funtion of temperature. Also A is given by relation $A = kV$ in the first approximation. The value of n decreases with rising in temprature as expressed the relation as follows ;

$$n = B \exp(-\alpha T)$$

where B and α are constant respectively. For α, the value is about 5.4×10^{-3}.

For perthite, an interesting phenomenon was found. In the lower temperature region, the current after application of field increases with time, but in the region of higher temperatures above 500°C it changes in a similar way to that observed in quartz or general dielectrics.

In both cases of quartz and perthite, the polarization e.m.f. in the region of sufficiently high temperatures is so small that it is negligible. Consequently, it is said that at higher temperatures above 600°C the electrical conductivity of rocks can be measured by using direct current since the polarization e.m.f. decreases with rising in temperature and the conductivity, on the contraly, increases steeply as raise the temperature.

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